

# Learning Elementary Physics through Haptic Simulations

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## ABSTRACT

Because many concepts in physics are non-engaging and difficult to understand, instructors in physics are challenged to fully engage students in the study of physics. For even the best students, current practices are not fully engaging and do not provide a deep understanding of fundamental principles. While traditional laboratory exercises are a good way to support and reinforce learning, haptic simulations can be more effective. Haptic feedback can increase understanding within a virtual environment in certain instances and can provide an additional modality for imparting tangible principles. In this paper, we discuss the design of an educational simulation tool using audio, visual and haptic feedback for learning basic concepts in physics at the elementary school student level.

## Categories and Subject Descriptors

H.5.2 [Information Interfaces and Presentation]: User Interfaces – *Haptic I/O, Graphical user interfaces (GUI)*.

## General Terms

Design.

## Keywords

Education, haptic, simulation based learning, virtual reality, e-learning, haptic feedback, physics, school education, K12, teaching innovation, technology enhanced learning, ICT.

## 1. INTRODUCTION

The visio-haptic virtual elementary physics simulation is an application of haptics, which involves the use of hand-eye coordination and the sense of touch in helping elementary school students understand concepts in physics.

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We have designed and developed simulations for basic concepts in physics such as weight change due to gravity, magnetic force, frictional force and viscosity. This work creates a learning simulation tool that aims to be exciting, engaging, and interesting for the students. Students can use this tool as a game and easily understand the concepts. It integrates haptics, graphics and audio.

A detailed tutorial that explains formulas and background theory for each concept is also included. Students can select topics from the given list. When a particular topic is selected, the student can touch, feel and interact with the objects in the screen with computer simulations via haptic interfaces (haptic devices). The devices are represented as virtual objects on the screen, and users can move and apply force to the virtual objects through the haptics device. Users receive the force feedback through these devices, and also receive visual feedback through the monitor and audio feedback. This interactive learning creates a more positive and effective learning environment than the traditional methods.

## 2. STATE OF ART

Haptic technology can be tactile or kinesthetic and recreates the sense of touch by applying forces, vibrations, or motions to the user through haptic devices, simulations and interfaces. Computer haptics is the area that focuses on the design and development of engineering systems and interfaces to create haptic virtual environments and simulations.

More generally, mainstream haptics have been focusing on standard applications in medical, chemical, virtual design prototyping, immersive gaming and entertainment etc. [1] and are commonly used as learning simulation tools for motor skill training and enhancement in the above elite fields [2][3][4]. Apart from training elite motor skills, haptics have the potential to be a teaching and learning tool for the intuitive perception of volumetric scientific data. A haptics enhanced education is an effective method of teaching and learning the basic scientific concepts in physics that are difficult to understand [5].

Harvey and Gingold [6] developed a visio-haptic simulation for 3D representation of atomic orbitals and Konrad J Schonborn [7] developed a haptic virtual model for bio molecular binding to improve student learning for these specific concepts that are traditionally difficult for chemistry students to conceptualize. The results have cognitive and practical implications for the use of multimodal virtual reality technologies in educational contexts [7]. Recently, Minogue et al. [8] examined the cognitive and affective impact of haptic feedback on students' conceptual understandings of the structure and function of an animal cell. Jones et al. [9] conducted an experiment to examine haptic feedback in the context of an investigation of viruses and explore how and why hands-on haptic experiences may be effective. Jonathan P San Diego et al. [10] proposed hapTEL, a virtual

learning system within an HE healthcare education setting describes the impact of Technology Enhanced Learning (TEL) and online simulations on the quality of learning, teachers, pedagogies, and on curriculum integration.

Gary R. Bertoline et al. [1] investigated the potential positive learning effects of additional haptic sensory feedback to computer visualizations in the context of learning electromagnetic field concepts. Christopher Richard and Allison Okamura [11] developed low cost, single-axis force reflecting joysticks and they were used to teach students about electromechanical systems, dynamics and controls. M Manivannan et al. [5] concluded that the integration of computer simulation based on the equations of motion and a haptic device would play an important role in the teaching/learning process of mechanisms. Tiberiu Butnaru et al. [12] presented a methodology and a prototype system for teaching and intuitive learning of mechanisms in mechanical engineering courses by using a custom made 1 DOF haptic system with augmented reality techniques. Ali Nahvi et al. [13] presented a haptic display system for manipulating virtual mechanisms derived from a mechanical CAD design to aid the design process by providing haptic feedback.

Han et al. [14] indicated that haptic augmented simulations were more effective than the equivalent non-haptic simulation in providing perceptual experiences and helping elementary school students create multimodal representations of the movements of gears. Eric N. Wiebe [15] proposed a simulation on the principles of levers, using both visual and haptic feedback and the learning scores, eye tracking, and lever push video analysis data, which were triangulated to provide a better understanding of how haptic feedback influenced learning outcomes. The results indicating that haptic feedback may have induced students to spend slightly more time interacting with levers.

Felix G. Hamza-Lup et al. [16] developed a visio-haptic simulation for the Coriolis effect to enable students to observe and feel the motion of an object and the forces acting upon it while moving over a rotating frame of reference, whether airborne or at the surface. Robert L. Williams II and Meng-Yun Chen [17] [18] developed computer simulations to enhance teaching elementary school physics with passive vibration feedbacks using the joystick devices.

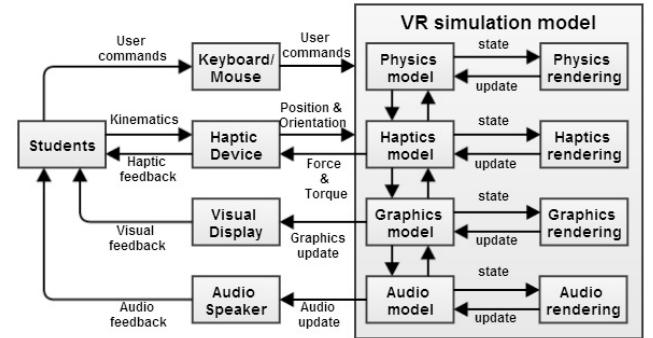
Recent research conducted by Graziano et al. [19] and Ernst et al. [20] showed that the human nervous system combines visual and haptic information in a statistically optimal fashion. Gary R. Bertoline et al. [1] suggests that inherently dual-modal stimuli, such as a variety of Physics' forces (spring force, electro-static force, gravitation, etc.,) that require both spatial and haptic cognitions, may be better understood when both modalities are involved in learning semantics of related physics phenomena.

In our previous work, Bhavani et al. [21] demonstrated that with the enhanced vocational education and training through the application of multimedia, virtual reality and haptic technology has the capacity to convey complex concepts and skill sets to illiterate and semi-literate individuals. Akshay et al. [22] also designed and developed a multi-tool cost effective haptic trainer that could potentially replace traditional training tools and materials in the primary stages of vocational skill training with audio, visual and haptic cues which would help the novice master use the tools in the absence of a human trainer. Along the same lines, J.Jose et al. [23] designed and implemented the TryStrokes application for brush stroke training and evaluation in our ongoing

Fabric painting course, using a Wacom tablet and stylus pen with brush attachments with real haptics effects.

Apart from training elite skills, the haptic simulator or haptics enhanced education proposed in this paper helps bridge the gap between limited education and learning abstract physics concepts for elementary school students. Although the exact perceptual role of the haptic modality in learning is still under investigation, this study could be applied to pedagogical contexts where virtual visio haptic models are envisioned for the construction of abstract, yet core, scientific concepts.

### 3. SYSTEM DESIGN & ARCHITECTURE



**Figure 1. Simulation Architecture Block Diagram.**

The system primarily consists of two sections as shown in Figure 1.

#### 3.1 Input and output devices

This Physics simulation application used the keyboard and mouse as the primary input devices and computer monitor display, and the audio speaker as the primary output devices. Novint falcon haptic device acted as both input and output device for the force feedbacks. Students can request the user commands to the simulation GUI for selecting the various sub sections through the computer mouse and keyboard. When students selected one sub simulation, and the mass, the haptic device acts like a 3D mouse pointer and the students can move the device probe in the device workspace; the corresponding virtual probe moves in the simulation virtual 3D world.

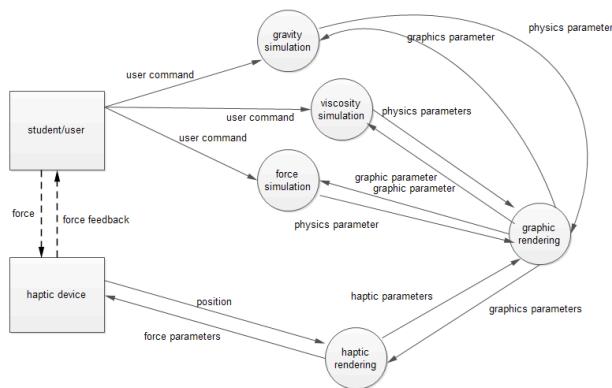
The simulation model renders the haptic, visual and audio updates and passes them to the haptic device, visual display and speakers. Thus the system provides haptic, visual and audio feedbacks to students through these output devices.

#### 3.2 Physics Simulations

We developed haptics based physics simulation modules with the combination of computer graphics and tutorials for four major physics concepts: gravity, viscosity, frictional force and magnetic force. This work is intended to introduce basic concepts of physics for elementary school students. In this work, we integrated and used the haptic technology and computer graphics in the learning procedure.

Simulation GUI is developed using Adobe flash and the haptic simulations were developed using Chai 3D. GUI provides students with the selection window needed for selecting four physics simulations as shown in Figure 1. Once students select one of the physics concepts, GUI provides a basic tutorial including the details of the concept and then the corresponding

VR 3D simulation developed by the Chai 3D library. The tutorial will help student understand the concept quickly and clearly. When a particular topic is selected, student can touch, feel and interact with the objects in the screen using haptics device and will get the feedback in the form of force. The dataflow between the students, simulations, and the haptic device is shown in Figure 2. In all these simulations, students can change simulation parameters for enhanced learning.



**Figure 2. Simulation Dataflow Diagram.**

### 3.2.1 Gravitational Weight Simulation



**Figure 3. Gravitational Weight Simulation Interface.**

Gravity is a force that attracts all physical objects towards each other. The greater the mass of an object, the stronger the force of gravity. In this simulation, UI is divided into 4 vertical sections corresponding to the Earth, Moon, Jupiter and Space. These sections are shown in Figure 3. We developed a physics model for this simulation and setup gravitational parameters for these different regions. The simulation also provides a range in mass of object (1 kg, 2 kg and 5 kg).

Simulation start by asking students to select a mass. When the mass is selected, students can feel the scaled weight in haptic device probe which is held by the student. After selecting the mass, students are then asked to move the virtual probe through the various regions- from the Space region to Earth, Earth to Moon, and Moon to Jupiter region, in the simulation environment. At each region, the simulation engine calculated the modified weight of the object based on the physics model and the selected mass using the equation  $W = m * g$ ;  $m$  is the mass of the object,  $g$  is the acceleration due to gravity in the region and  $W$  is the

calculated weight of the object in the region).  $W$  is a force vector acting downwards and sending it to haptic device. Students can feel the weight difference when the probe moves from different regions. Students can move the selected object using haptics device through different places (Earth, Moon, Jupiter etc.) and feel the mass of the object in all the places and can compare the mass for varying places.

Because there is no gravitational force in space, the weight of the object is zero and so the user does not feel any weight in the space regions. When probe objects are moved to the Earth region in the simulation, students can feel the weight which is calculated using the acceleration due to gravity in Earth ( $9.81 \text{ m/s}^2$ ). When the object is moved to Moon region, the weight is reduced because of the reduced acceleration due to the gravitational force on the Moon ( $1.6249 \text{ m/s}^2$ ). When the object is moved to the Jupiter region, the weight was increased because of the higher acceleration due to gravity on Jupiter ( $24.79 \text{ m/s}^2$ ).

The haptic model of the simulation creates a scaled force vector for the gravity simulation and sends it to the haptic device. Through the haptic device, students can feel the change in weight due to the changes in gravity in the different planets and regions. Through this simulation, students get a chance to feel the physics concepts with visual and audio feedbacks.

### 3.2.2 Viscosity Simulation



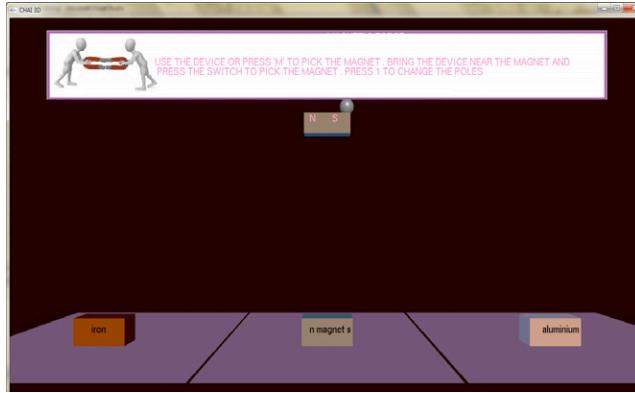
**Figure 4. Viscosity Simulation Interface.**

Viscosity is a measurement of how resistant a fluid is to an object as it attempts to move through it. This simulation module allows the students to feel the viscosity of a selected fluid. Different types of fluids (water, honey, oil, etc.) are available in the GUI for the selection as shown in Figure 4. Students are asked to select a type of fluid, and the weight of an object to put into the fluid from simulation GUI. For each fluid, the coefficient of viscosity is fixed, but user can change the weight of the object that is put in to the fluid. The position of the avatar (haptic device probe inside the virtual environment) is calculated and is passed to the collision-detection algorithm. The collision-detection algorithm uses positional information to find collisions between fluid and avatars.

To simulate viscosity, the force-response algorithm computes interaction forces between avatars and fluid involved according to the damping model, and sends it to the haptic device. Viscous feedback force  $F_b = -b * v$ ;  $b$  is the damping coefficient and  $v$  is the instantaneous velocity vector of the haptic device probe. Students can feel the weight of the object and the viscosity of the fluid, and can also compare the viscosity of different fluids through the haptic device.

### 3.2.3 Magnetic Force Simulation

A force is a push or pull upon an object. The user can select one of two types of forces-either the force of friction or magnetic force, and apply the force to an object on the screen. Once the force is applied, the user can see the motion of the object and feel the effort required.



**Figure 5. Magnetic Force Simulation Interface.**

This simulation activity allows user to feel the magnetic force between magnets, magnetic materials, and non-magnetic materials. As shown in Figure 5, from the magnetic force simulation GUI, students can pick the magnet using the haptic device and moves the magnet to a magnetic material (Iron), to another magnet and a non-magnetic material (Aluminum). The magnetic force is affected by the distance between the object and magnets, and the strength of the magnetic field. We implemented the linear model for magnetic forces. As soon as the device enters this zone of magnetic field, it exerts a force of attraction on it. The force of attraction and repulsion change linearly according to the distance between them.

Through this simulation students can feel and learn about the magnetic attraction force and repulsive forces. The students can see and feel the effort required when distances between the magnet and the material changes, and can compare the results for various materials.

### 3.2.4 Frictional Force Simulation



**Figure 6. Frictional Force Simulation Interface.**

Friction is a force that is created whenever two surfaces move or try to move across each other. Friction always opposes the motion or attempted motion of one surface across another surface. Friction is dependent on the texture of both surfaces. It is also dependent on the amount of contact force pushing the two

surfaces together (normal force). In this simulation, as shown in Figure 6, students can choose the weight of the moving object as well as the sliding surface. Students can then move object through sliding surface.

There are two types of frictional forces: those arising from static friction, and those arising from dynamic friction. The coefficient of friction between two surfaces is a measure of the degree to which the two surfaces resist moving with respect to each other. There are two coefficients for any two surfaces in contact with each other, the coefficient of static friction ( $\mu_s$ ) and the coefficient of dynamic friction ( $\mu_d$ ). The frictional force between two surfaces is proportional to this coefficient,

$$F_d = \mu_d * F_n$$

$$F_s = \mu_s * F_n$$

Where  $F_n$  is the normal force with the surface,  $F_d$  is the dynamic frictional force,  $F_s$  is the static frictional force and  $\mu_d < \mu_s$ .

On a level surface, the normal force ( $F_n$ ) is always equal and opposite to the weight. The force of static friction ( $F_s$ ) cancels out the applied force right up to and including when static friction reaches its maximum ( $F_s$  max). For applied forces greater than the maximum force of static friction, the block starts to slip and then the value for friction becomes kinetic friction ( $F_d$ ). The box is then under a net force so it accelerates to the right. Students can pull objects on the screen through different surfaces using haptic devices. The user can see the motion of the object and feel the effort required. The user may also change the weight of the objects, and then feel different input forces.

We used the frictional cone algorithm implemented in Chai 3D, as proposed by Harvin et al. [24] to display effects of friction in haptically enabled VEs in harmony with god-object algorithm. Assuming a locally planar surface, the frictional cone intersects the surface in a circle. The frictional cone is determined based upon the coefficient of friction ( $\mu$ ) and depth of penetration ( $d$ ). Along the surface, as long as the coefficient of friction remains constant, the radius of this circle is decided by the depth of the penetration  $r = d \cdot \mu$ , where  $r$  is the radius of the frictional cone.

## 4. CONCLUSION

This paper presented a visio – haptic virtual physics simulated learning tool mainly intended for elementary school students to teach abstract physics concepts. The tool allows students to better understand different concept in physics by introducing a tangible learning component. Students are able to feel the effects of forces through the haptic device and virtual simulations. Tutorials that explain the exercises and physics concepts are included for the users. Keyboard events are added for better user interaction with the system. This system provides an easy to learn interactive experience. Users can experience effective interactions and exchange information between user and system in multiple ways through audio, graphics and haptics.

From various standpoints this product is useful for students, even with students who are challenged with visual impairments and the user interface has been designed with this usability factor as a prime motivator.

Other features that enhance the student's learning experience are:

Multimodal feedback: When the user gives an input through the haptic device, he or she will get haptics, as well as audio and visual, feedback.

User engagement: The inclusion of haptic feedback conveys rich and detailed information about the concepts in a fun learning setting. When it is combined with other senses, especially sight and touch, students can understand the concepts more clearly and much quicker.

Dealing with Complexity: For each concept, a detailed tutorial section is included which will help students to further their theoretical understanding and assimilate the equations that produce the results experienced in the respective concepts.

## 5. FUTURE WORK

In terms of future work, we seek to deploy and evaluate this tool within an elementary school educational setting, and implement user feedback to improve the use of the application. For now, we have scaled down the force feedback to suit the force resolution of haptic device that can be improved upon. We also can benefit from smoothening the haptic feedback in certain instances. We further plan to implement other physics concepts into the program that are difficult to understand. We also intend to improve the game by enhancing the user interface and interactive tutorials to support the simulation.

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